CAPTURE OF COMETS DURING THE EVOLUTION OF A STAR CLUSTER AND THE ORIGIN OF THE OORT CLOUD

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Abstract. It is generally assumed that the Solar System is surrounded by a swarm of comets, the so-called Oort Cloud, which contains approximately \(10^{11}\) members. The observed comets belong to a small subsection of the Cloud, and they have very elongated orbits. The origin of the Cloud is presently unclear. Here we consider the possibility that the comets were born in a star cluster together with the Sun. We follow the evolution of the star cluster with its embedded swarm of comets and calculate the rate at which stars accumulate stable comet companions. We conclude that if the Oort Cloud of comets was born in this process, then the present day density of comets in interstellar space has to be high, and that comets make a significant contribution to the overall mass density of the Galaxy.

Keywords. Oort cloud, comets, origin of comets, capture of comets.

1. Introduction

It is usually accepted that the solar system is surrounded by a huge cloud of long-period comets, the so-called Oort Cloud (Oort, 1950). The number of comets in the cloud is estimated to be in the range of \(10^{11} - 10^{12}\) (Weissman, 1982), and the cloud extends out to \(\sim 10^5\) AU. The large extent of the cloud in comparison with the planetary system has cast doubts on whether the comets may be original members of the Solar System at all; in principle they could be captured members of the interstellar medium (McCrea, 1975). However, problems arise with the low probability of capture of interstellar comets (Valtonen and Innanen, 1982).

Here we consider another scenario of the interstellar origin of comets, in which stars and comets are born together in an interstellar cloud of gas. Donn (1976) argues that comet formation would be a natural extension of star formation in interstellar gas clouds. We will consider the dynamical consequences of this proposal. We derive the probability of capture of comets by a single star which leaves the cluster. Finally we scale the results to the cometary system of our Sun, and derive the resulting density of comets in the interstellar space.

2. The Model

We place \(N\) stars randomly in a sphere of radius \(R_0\) and assign them random uniform velocities in a sphere in velocity space. We consider two cases. Case I: The system is in

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Figs. 1. The fractional number of stars (solid line) and comets (dashed line) $N/N_0$ in case I-model 2 in intervals of radial distance $R$ from the center of the cluster, at two different times $T$ of evolution.

Virial equilibrium, i.e. the total kinetic energy equals half the absolute value of the potential energy. Case II: The system expands parabolically, i.e. the total kinetic energy equals the absolute value of the potential energy. Case I describes an isolated star cluster, born from a non-expanding interstellar cloud of gas. However, there are many tendencies in real clusters to disrupt the steady evolution, e.g. the tidal force of the Galaxy and the mass loss due to stellar evolution. We will not attempt to model all the complications of the real clusters but calculate Case II as an extreme case of a cluster under disruption.

The orbits are integrated by using the program by Aarseth (1971). We will mainly study the evolution of the cometary system since similar and more detailed studies of the stellar system have been carried out previously (e.g. Aarseth, 1974). Therefore we populate the cluster with about a thousand massless particles – comets. Initially the comets reside in the same sphere of radius $R_0$ and have the same velocity dispersion as the stars. The orbits of comets are integrated in the same way as the orbits of the stars.